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Case Report
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Motorboat Propeller Injuries: Report of Thirteen Cases with Review of Mechanism of Injury and Bacterial Considerations

Charles T Price[1]*, Michael J. Muszynski[2], Julie A Zielinski[3] and Charles Stewart[4]

[1]*Arnold Palmer Hospital for Children, Orlando, FL, USA*
[2]*Florida State University School of Medicine, Orlando, FL, USA*
[3]*T.C. Thompson Children's Hospital, Chattanooga, TN, USA*
[4]*Boca Raton Orthopedic Group, Boca Raton, FL, USA*

Abstract

Background: Motorboat propeller strikes can cause devastating injury due to injury mechanics and complex contamination. The frequency of these injuries has been under-reported. This paper provides a review of propeller injuries admitted to our hospital over a six-year period. Discussion includes injury mechanics, initial management, literature review, accident statistics, and possible prevention measures.

Methods: Charts of all patients admitted to our hospital following boating injury were reviewed. Thirteen patients were identified with motorboat propeller injuries. A review of boating accident statistics during the same period of time was also conducted.

Results: Patients averaged 2.8 surgical procedures during the initial hospitalization. Infections developed in 46% of patients and there were five amputations in three patients. During the period of this study the number of reported propeller or skeg boating accidents increased from 8 per year to 80 per year in Florida.

Conclusions: Motorboat propeller injuries can be extensive due to severe mechanical damage and contamination with uncommon marine organisms. Blood loss and contamination may be underestimated at time of admission. Therapeutic triple antibiotic management and frequent irrigation and debridement are recommended. Multiple surgical procedures and extended hospitalization are often required with lifelong physical impairment as the final outcome. The apparent increase in reported injuries probably reflects improved accuracy of reporting rather than true increase in frequency of these injuries. Safety education and enforcement along with development and implementation of safety devices is recommended.

Keywords: Boating; Injury; Propeller; Accident; Statistics; Open fracture

Introduction

Outboard motorboat propeller strikes can cause devastating injury, infection, and death. Approximately 10%-15% of propeller injuries are fatal [1,2]. Motorboat propeller injuries present management problems that may be unfamiliar to trauma surgeons because of the mechanism of injury and bacterial contamination from underwater impact. Severity of injury and complex contamination may not be apparent on initial inspection. It has been noted that these injuries are underreported even though laws are in place requiring all boaters to report boating accidents and injuries to local and national authorities [3]. This paper provides a review of all propeller injuries admitted to Orlando Regional Medical Center during a 6 year period. The mechanical aspects of propeller injuries are presented along with a literature review and recommendations for initial evaluation and management.

Methods and Materials

With approval from our Institutional Review Board and assistance from the health information management office and coding department at Orlando Health Systems all hospitalized patients with ICD-9 and e-codes pertaining to boating injuries were identified between October 2003 and August 2009. A total of 267 patient encounters were identified in this time period. Further review of those 267 charts identified 13 patients with propeller related injuries. Demographic information, injury and treatment data, complications and outcomes were analyzed.

Results

Between October, 2003, and August, 2009, 13 patients were admitted to our hospital for management of propeller related injuries. These injuries ranged in severity from superficial lacerations that did not require closure to severe, devastating injuries with limb loss (Table 1). No patients died of propeller injuries after reaching the hospital during the period of this study. Five of the injuries occurred at very low speed (estimated less than 5 mph) including one patient with two amputations. Five occurred at speeds that were estimated to be greater than 10 mph. Three records did not provide enough information to estimate boat speeds. Eleven injuries occurred in fresh water, one in salt water, and one occurred while on land. Fall from a boat prior to propeller strike occurred in seven patients. Four were in the water from skiing or other activities when struck. The sequence of injury could not be determined for one patient (#9), and one propeller injury occurred while on land.

***Corresponding author:** Charles T Price, Arnold Palmer Hospital for Children, Orlando, Florida 1222 S. Orange Ave, Fifth Floor, Orlando, FL 32806, USA, Tel: 1 321-843-5271; E-mail: charles.price@orlandohealth.com

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Pt	Sex	Age (yrs)	Injury	Length of stay initial hospitalization (days)	Initial antibiotics	Surgical procedures initial hospitalization	Blood Transfusion	Infection	Timing of Infection	Amputation	Mechanism and water
1	M	48	Multiple complex deep lacerations right leg	26	cefazolin, gentamicin	6	4 units	*Candida tropicalis,*	1 week	No	Fall and struck by propeller at moderate speed. Fresh water
					piperacillin-tazobactam, vancomycin			*Pseudomonas fluorescens; Klebsiella pneumoniae*	7 weeks		
2	M	27	Complex lacerations right thigh Deep laceration left knee	4	cefazolin then changed to piperacillin-tazobactam	2	0 units	None	NA	No	Dragged into prop in fresh water during water ski pick-up low speed
3	F	35	Right transhumeral amp, left thumb amp, left hand lacerations	3Elective transfer after initial surgical stabilization	cefazolin, gentamicin	1 (Additional procedures elsewhere)	4 units	None	NA	Right above elbow and left thumb amputations – acute/ traumatic	Salt water, pushing boat off sand bar and fell into propeller
4	M	32	Right posterior leg lacerations, complex open foot fractures	8	cefazolin, gentamicin, ciprofloxacin	5	0 units	*S. aureus* (MSSA)	4 months, following flap surgery	No	Fresh water, wake boarding. Struck during pick-up in water slow speed
5	M	50	Complex forearm lacerations	3	clindamycin, gentamicin	2	0 units	*S. aureus* (MSSA)	2 Days	No	Fresh water, In water after fall from jet ski. Struck by oncoming boat at unknown speed
6	M	27	Deep foot laceration, no tendon or bone involvement	1	none	1	0 units	None	NA	No	On land, slipped and cut foot on exposed propeller blade
7	M	37	Deep laceration leg with tendon involvement	3	cefazolin, gentamicin	1	0 units	None	NA	No	Fall and struck by propeller at moderate speed. Fresh water
8	F	10	Bilateral multiple complex thigh lacerations, right open femur fracture	34	cefazolin, gentamicin	8	4 units	*S. aureus* (MSSA)	8 weeks: infected vascular graft in open wound	Bilateral AKA after initial salvage attempts	Fall and struck by propeller at moderate speed. Fresh water
9	M	20	Left foot open fracture	3	ceftriaxome, changed to cefazolin	1	0 units	None	NA	No	Struck by propeller, speed and water not noted in chart
10	M	15	Bilateral lower extremity multiple lacerations, left AKA, lacerations to back/flank/ gluteus	8	piperacillin-tazobactam	7	6 units	*Acinetobacter baumannii,* (MRSA, MSSA)	1 day, 5 weeks, 11 months, respectively	AKA acute/ traumatic	Fall and struck by propeller at moderate speed. Fresh water
11	M	43	Left forearm and lower extremity, multiple complex lacerations	3	cefazolin	3	2 units	*S. aureus* (MSSA)	Both at 4 weeks	No	Fall and struck by propeller at moderate speed. Fresh water
								Shewenella denitrificans			
12	M	24	Neck and back, superficial abrasions and minor lacerations (left open due to contamination)	1	oral amoxicillin-clavulanate	0	0 units	None	NA	No	Fall and struck by trolling motor at low speed. Fresh water

13	M	53	Flank multiple superficial lacerations (left open due to contamination)	2	cefazolin	0	0 units	None	NA	No	Fell, struck by boat with LOC and minor prop injuries, fresh water
Avg		32		8		2.8	1.54 units				

Abbreviations: MSSA-methicillin-sensitive *Staphylococcus aureus*; MRSA-methicillin-resistant *S. aureus*; amp-amputation; AKA-above knee amputation; LOC-loss of consciousness; NA-not applicable

Table 1: Propeller related injuries.

The average patient age was 33 years with a range of 10-53 years. Two of the 13 patients were female. Nine patients sustained injuries to the lower extremities and four to the upper extremities. Average length of stay was 8.0 days (range: 1 to 34 days), and average number of trips to the operating room for wound management was 2.8 (range: 0 to 8). Five patients (38%) required blood transfusions. There were five amputations in three patients. Three amputations occurred at the time of injury or initial debridement and two were delayed amputations. Amputations included a proximal trans-humeral amputation, thumb amputation, and three above knee amputations.

Infections developed in 46% of patients (6 patients) with the most common being Staphylococcus aureus in 5 patients. Other organisms included *Candida tropicalis, Pseudomonas aeruginosa, Acinetobacter baumannii, and Achromobacter denitrificans*. Half of the infections occurred during the initial hospitalization. The injuries were managed by various physicians with considerable inconsistency in antibiotic treatment. Nine patients were initially given cefazolin. Antibiotic therapy was adjusted in 8 patients to broader spectrum coverage, including gentamicin, piperacillin-tazobactam, ciprofloxacin, and clindamycin. There were five deep infections and one superficial infection diagnosed more than one month after the date of injury

Case Example

Patient #10 was a 15-year-old-male who fell from the bow of a boat as it turned. He passed under the boat and was struck by the propeller. He sustained multiple deep wounds over the back, gluteus, and both lower extremities. Massive bleeding occurred from multiple deep wounds with nearly complete amputation through the left thigh. Above knee amputation was completed at the time of initial debridement. Figure 1 shows his right foot with deep parallel lacerations characteristic of propeller cuts. He required four units of whole blood plus intravenous fluid resuscitation and subsequent administration of two units of packed red blood cells. Antibiotic coverage was initiated in the emergency department with an aminoglycoside and cefepime. Initial debridement included completion of the left mid-thigh amputation. Seven surgical procedures for debridement and reconstructive procedures were required during his initial hospitalization. Antibiotic therapy was changed to meropenem when *Acinetobacter baumannii* was isolated from blood culture. He was transferred to a rehabilitation facility after 8 days, but was readmitted five weeks after initial injury due to methicillin-resistant *Staphylococcus aureus* (MRSA) soft tissue infection of the heel and was treated with vancomycin. The MRSA isolate sensitivities were consistent with community-acquired MRSA. Eleven months following his injury he developed a superficial infection with methicillin-sensitive S. aureus (MSSA) that responded to oral cephalexin. At the time of this report he has reached maximum improvement and has returned to athletic activities while using a sports-specific above knee prosthesis.

Figure 1: Right foot with deep parallel lacerations.

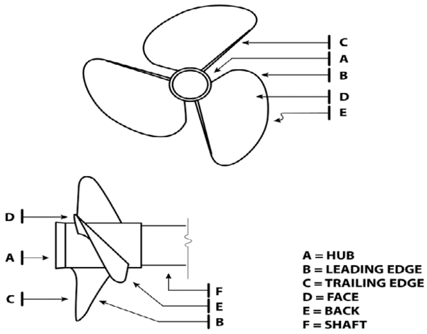

Figure 2: Propeller design.

Discussion

Injury mechanics and fluid dynamics

Injuries created by propellers are complex. The propeller (Figure 2) is comprised of a central hub attached to the rotating drive mechanism. From the hub, extend several blades, usually 3-4. Each blade has a face and a back. The "face" faces aft, or away from the boat and is the positive pressure side. It pushes water when the boat is moving forward. The "back" faces the boat and is the negative pressure side. It sucks water into the propeller. The complexities of the curvature and configuration of the blades are beyond the scope of this paper. As the propeller turns, a pressure differential is created between the negative back and positive face, leading to ventilation (air sucked down from the surface) and cavitation (a vacuum phenomenon). Either can draw objects, clothing, and extremities into the path of the blade. A 'cupped' or curved blade reduces cavitation and provides a stronger blade, which allows for a thinner design and better efficiency for the watercraft [2]; however, a thinner blade also slices tissue more easily. Other components of the motor such as the skeg or cavitation plate can also inflict injury (Figure 3).

Propulsion follows a screw mechanism. The pitch of the blade relates to forward progression of the vessel similar to screw pitch. A blade with a 15 inch pitch will advance 15 inches in one revolution. A standard 3-blade propeller at 3200 revolutions per minute (rpm) will impact 160 times in one second [4]. This equates to the propeller travelling the length of a 6 foot tall man (1.83 m) in 0.08 seconds with 14 strikes, if he does not get caught and without slip. The human body is

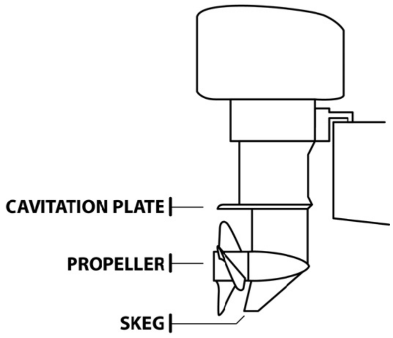

Figure 3: Cavitation plate.

approximately the same density as water and reacts to a propeller strike in a similar manner with regard to fluid dynamics. The drag coefficient is the drag of an object in moving fluid. The amount of drag depends on several factors including speed of movement, size and shape of an object, and the density of the fluid [5]. Water is approximately 50 times more viscous than air, so the drag coefficient is approximately that much greater than the drag coefficient of air [6]. Higher drag forces make it more difficult for the person to be pushed away after being hit by an object under water. Once hit, the drag resistance will keep the individual close while the propellers continue to spin. Conversely, in air, after the first strike the individual or extremity will be bounced or pushed back with little to no resistance from the air.

Injury evaluation and initial management

Wounds may range in severity from innocent appearing lacerations to massive, complex trauma with vascular and neurological involvement. Management protocols should consider size and location of wounds, associated injuries and level of contamination in order to tailor treatment to specific needs. Comprehensive wound management for severe open injuries [7,8] is beyond the scope of this paper, but there are some unique aspects of propeller injuries that should be considered.

Patients who survive may or may not have extensive blood loss, but first responders might underestimate the extent of hemorrhage because there are few visual clues regarding the volume of blood lost in the water. Wound necrosis may also be difficult to predict initially and may develop in a delayed manner due to parallel lacerations that impair circulation. Increased metabolic demand because of contamination and inflammation may also contribute to delayed ischemia. Shorter intervals between debridement may advisable depending on severity of contamination and the potential for delayed necrosis. Propeller lacerations expose deep tissues to severe contamination along with exposure to unusual water-associated organisms. However, the severity of contamination may be underestimated due to the absence visual clues, such as dirt and other foreign material. As the propeller creates a laceration, the water on the high pressure side is forced into the wound creating a cavity similar to jet injection injuries. Organisms may be impelled deep into the contused or devascularized tissue. Oceans, lakes and inland waterways that are suitable for boating contain as many as 10^7 microorganisms/mL of water and as many as 180 species have been isolated from various waters [9]. Aquatic injury environments are commonly classified as freshwater, marine (salt) water-related, or contained water sources (swimming pools, hot tubs, whirlpools, and fish tanks) [10]. Early consultation with infectious disease specialists should be considered in these cases. It is also useful to alert the microbiology

Organisms common to both freshwater and seawater	Notes	General antibiotic sensitivity
Gram-negative enteric organisms	High bacteria numbers in areas of sewage drainage	Fluoroquinolone, 3rd and 4th generation cephalosporin, aminoglycosides
Gram-negative non-fermentors (*Acinetobacter* and *Alcaligenes* spp)	Acinetobacter spp is the most important	Cefepime, carbapenem (meropenem, imipenem)
Staphyloccoci (including *S. aureus*)	Also skin commensal as the source	Anti-staphylococcal penicillin, cephalosporin, vancomycin (MRSA)
Streptococci (including *S. pyogenes* and enterococci)	Also skin commensal as the source	Anti-staphylococcal penicillin, cephalosporin
Bacillus spp	Most common in soil contaminated water	Carbapenem, vancomycin, clindamycin, fluoroquinolone
Anaerobes (especially *Clostridium* spp)		Carbepenem, clindamycin, cefepime
Candida spp	Also skin commensal as the source	Amphotericin, azoles
Freshwater organisms		
Aeromonas spp	Most common in fresh and brackish water	Fluoroquinolones, TMP-SMX, aminoglycosides, carbapenem
Pseudomonas aeruginosa	Most common in freshwater	Cefepime, piperacillin-tazobactam or meropenem plus aminoglycoside; fluoroquinolone
Plesiomonas shigelloides		quinolones, tetracycline, TMP-SMX, cefepime
Edwardsiella tarda	Exclusive to freshwater	Extended spectrum ß-lactams, aminoglycoside, fluoroquinolone
Chromobacterium violatium	Stagnant freshwater	Fluoroquinolone
Shewanella (*Achromobacter*) spp	Uncommon in saltwater	3rd and 4th generation cephalosporin
Seawater organisms		
Vibrio spp	Most significant marine trauma pathogen	Fluoroquinolone (ciprofloxacin), doxycycline plus ceftazidime or cefepime
Aeromonas spp	Also found in sea animal bites	See under freshwater above
Pseudomonas aeruginosa	Also found in sea animal bites	See under freshwater above
Erysipelothrix rhusiopathiae	Exclusive to seawater	Penicillin, cephalosporin, fluoro-quinolone
Mycobacterium marinum	Exclusive to seawater and aquaria	Clarithromycin, ciprofloxacin, doxycycline, TMP-SMX, may need other anti-tuberculosis agents

Abbreviations: MRSA: methicillin-resistant *S. aureus*; TMP-SMX: trimethoprim-sulfamethoxazole. (Table compiled from references [9-19]).

Table 2: Important organisms in water-associated infections after trauma.

Year	Prop/Skeg Primary Cause	Prop/Skeg Secondary Cause	Total Prop/Skeg Injuries
2004	6	2	8
2005	9	6	15
2006	9	26	35
2007	10	31	41
2008	15	45	60
2009	13	67	80

Table 3: Propeller/Skeg injury data from Florida fish and wildlife conservation commission.

laboratory as to the specific source of the wound contamination. Such information is germane to the microbiologist's approach to isolation of specific potential pathogens, the need for specialized growth media, as well as the accurate interpretation of culture results. In general, there are isolates common to all natural water sources and others which are more specific to the particular environment (Table 2). Isolates common to all sources include streptococci and staphylococci (both water-borne and skin commensals), Gram-negative fermenters (especially Enterobacteriaciae), *Pseudomonas aeruginosa*, *Aeromonas* ssp, a variety of other non-fermentative Gram-negative bacilli, and anerobes (especially *Clostridium* species) [10,11]. *Aeromonas* spp are more commonly found in freshwater and *Plesiomonas* and *Edwardsia* spp are almost exclusive to freshwater [11]. *Vibrio* spp and Mycobacteria are particular to ocean and marine waters. *Vibrio* species must be considered in all wound infections associated with seawater exposure and treated accordingly, since these infections are often severe, and delayed treatment is associated with higher morbidity and mortality [12,13]. Therefore the specific wound environment bears important implications for empiric antibiotic treatment. It would be prudent for initial antibiotic treatment for significant wounds to include coverage against beta-lactamase producing organisms, Gram-negative bacilli including *Pseudomonas aeruginosa* and *Aeromonas* spp. with added coverage for *Vibrio* spp for saltwater injuries [9,10,12]. This may be accomplished using a flouroquinolne (ciprofloxacin), or for severe injuries, a combination of an antipseudomonas cephalosporin (cefepime) or beta-lactam (piperacilline-tazobactam) or carbepenem (meropenem) plus an aminoglycoside (gentamicin), with the addition of doxycycline when Vibrio infection is possible. While doxycycline should not be used under the age of 9 years and flouroquinolnes should be generally avoided in children, the severity of Vibrio infection in the setting of severe marine injury can require their prudent use.

The etiologies of wound infection in our patients have all been described for water-related sources [10]. *S. auerus* and candida have been described as water-related or commensals. The MRSA strain isolated as a late infection from one patient had an antibiogram typical of community acquired isolates. The cases with *A. baumanii*, *Achromobacter denitrificans*, and *P. fluorescens* illustrate the risk for infection with multi-antibiotic resistant organisms. The patient (#10) with initial, then recurrent and later *A. baumannii* infection is illustrative of the challenge in treating wound infections due to this highly resistant organism. Such infections are often severe and difficult to treat and require extended treatment and multiple surgical procedures [14,15]. Delayed infections were noted in five of the 13 patients. All five were in severely traumatized and had undergone multiple debridements and reconstructive procedures. Delayed infections in traumatized patients are not uncommon because of multiple blood transfusions, relative immunosuppression, excessive contamination and impaired vascularity following wound healing or coverage flaps [16-18]. More frequent follow-up for these patients may be reasonable because delayed infections may be difficult to diagnose [16,17].

Injury statistics

The Florida Fish and Wildlife Commission reported a steady increase in the number of injuries caused by strikes from the propeller or skeg during the period of this study (Table 3). Under-reporting of propeller injuries has been noted in the past [2,3] and it may still be difficult to accurately assess the scope of the problem. Statistics are recorded by various government entities. The United States Coast Guard (USCG) maintains statistics for each state in the U.S.A [1]. The Florida Fish and Wildlife Conservation Commission also records boating accidents for the state of Florida [19]. These statistics are not always in precise agreement, and the U. S Coast Guard acknowledges that there are deaths and injuries that are not reported.

U.S. Coast Guard data indicates 13% of boating accidents occurred in Florida in 2008. Also, in 2008, the U.S. Coast Guard reported 181 propeller injuries for the entire United States. The Florida Fish and Wildlife Conservation Commission reported 60 propeller injuries in Florida in 2008. If this data is accurate, then Florida accounted for one in every eight boating accidents, but one in every three propeller injuries. It is possible that propeller injuries are more common in Florida, or that current reporting may be more accurate in Florida compared to the rest of the United States. Data from the Florida Fish and Wildlife Conservation Commission (Table 3) suggests that reporting in Florida is improving. Only 8 propeller injuries were reported statewide in 2004, compared to 60 in 2008, and 80 in 2009. There are many facets of injury data that are beyond the scope of this paper. Of relevance, is whether the propeller strike is reported as the primary or secondary event. If a passenger falls from a boat and is subsequently hit by the propeller, then the primary event is recorded as "fall from boat". Until recently, only the primary cause of accident was reported [3]. The number of propeller strikes reported in Florida has been increasing, but this may be due to improved reporting that includes primary and secondary events.

We treated three patients in 2004 and only eight were reported for the entire state. Four years later, in 2008, we treated two patients and 60 were reported in the entire state. It is our opinion that the increase in propeller/skeg injuries reported from 2004 to 2009 represents an improvement in accuracy of reporting rather than a true increase in the frequency of these injuries.

Prevention issues

In addition to boating safety education and enforcement, several safety devices have been identified to help prevent propeller strikes [4]. These include cut-off switches, propeller guards, ringed propellers, propulsion alternatives, sensors, and other devices [4]. A cut-off switch may prevent some propeller injuries if all occupants in the boat were connected. Safety propellers have also been designed with patents submitted or approved but these devices are not generally built into the motor/vessel nor provided by the motor manufacture at the time of initial purchase. Figure 4 shows a Pump Jet Propulsion System (ACT, Orlando, FL) that has a propless pump jet for outboard motors. This is designed to allow safe military training in water, particularly at night. Figure 5 show a cage type propeller guard. Approximately 20% of propeller injuries occur at speeds less than 10 mph, such as picking up a downed skier. In our patients approximately 40% of injuries occurred at speeds less than 5 mph. Propeller guards and other safety devices may reduce the risk of injury at these speeds. Propeller guards are installed on motors of inflatable rescue boats that are used for surf rescue in Australia, Los Angeles County, Denmark

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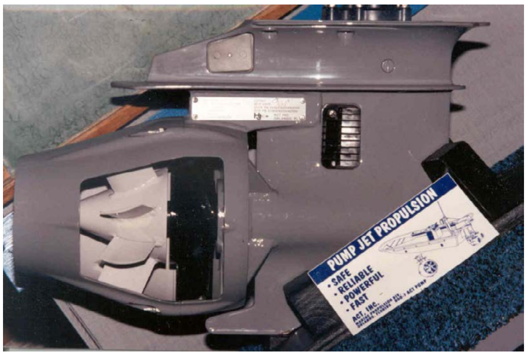

Figure 4: Pump jet propulsion system.

Figure 5: Cage type propeller guard.

and the United Kingdom. These guards are also used during surf rescue competitions. Objections to the use of guards include reduced efficiency, increased drag, poor motor performance, poor handling characteristics, increased fuel consumption, and ineffectiveness at high speeds. Boating safety initiatives include responsible boating practices. Alcohol consumption is a known factor in many boating accidents [1] but excessive alcohol consumption was not a reported factor for any of our patients. Many organizations including The United States Coast Guard promote boating safety**.** The USCG has produced a brochure regarding the danger of propeller strikes and some safety tips for prevention of propeller injuries [4]. Safety recommendations include use of a kill switch, assigning a passenger to observe for people in the water, never boarding or exiting the boat when the engines are on, never allow passengers to sit where they might be thrown into the water, and establishing clear rules for boarding and swim platform use. The USCG Propeller Strike brochure also recommends that boat owners consider purchasing a propeller safety device for their boat. The list of available devices includes propeller guards, ringed propellers, propulsion alternatives, and other options [4].

Conclusion

Boat propeller injuries may range from superficial lacerations to complex, devastating injuries and death. In addition to severe tissue damage and amputation, infection rates are high and include common and uncommon freshwater, marine, and soil associated bacteria. Our 5-year hospital-wide review showed a 23% amputation rate and a 46% infection rate, with half of those involving multiple organisms. Early consultation with infectious disease specialists should be considered in all cases. The injuries may require multiple surgical procedures and extended hospital stays. Blood loss requiring replacement occurred in 38% of our patients. Aggressive broad spectrum coverage including coverage for traditional pathogens as well as organisms prevalent in the water source in addition to frequent irrigation and debridement may help reduce the risk of infection. Propeller injuries have been under-reported although reporting accuracy seems to be improving. Prevention of these injuries begins with boating safety initiatives. Education and enforcement of safety regulations along with development and implementation of effective safety devices may reduce the frequency of these potentially devastating injuries.

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